

# INFLUENCE OF THE TYPE OF PLACE OCCUPIED BY A TRAM PASSENGER ON THE RIDE COMFORT

Lukasz BAKINOWSKI<sup>1,2</sup>, Bartosz FIRLIK<sup>3</sup>

<sup>1</sup> Modertrans Poznań Sp. z o.o.

<sup>2,3</sup> Faculty of Civil and Transport Engineering, Poznan University of Technology, Poznan, Poland

---

## Abstract:

*In cities with developed transport infrastructure, many people use public transport in their everyday lives. In order for the passenger's journey to be comfortable and for the passenger to travel more willingly by tram than by car, many conditions must be met. A passenger must feel comfortable in a public transport vehicle, which includes, among others: appropriate temperature in the vehicle, no crowding, the possibility to seat, the possibility of a quick vehicle-change, short travel time, no noise and many others. A very important criterion from the point of view of travel comfort is also the level of vibrations in the tram. A tendency can be noticed that vehicles with a low vibration level are rated much higher by public transport passengers and citizens. Vibration itself can also be an indirect cause of noise. The greater the noise, the greater the dissatisfaction of the passenger which indicates the high role of vibrations as a factor of passenger satisfaction or dissatisfaction. The aim of the work is to test and evaluate the vibration level in the partially low-floor Moderus Beta MF 02 AC tram manufactured by the company Modertrans Poznań in Poland. Assessed was the vibration comfort in selected points of the vehicle, including the floor and passenger seat. The level of vibrations in trams of the same type were compared. Due to the lack of specific Polish regulations regarding the permissible level of vibration in trams, an attempt was made to compare the obtained results with railway standards requirements or foreign countries requirements. The study proved that the level of vibrations differs in trams belonging to the same type. Significant damping of vibrations in the vertical direction by the passenger seat was observed. Maximum level of vibrations in the passenger area of the vehicle was observed on the floor above the bogie. It was found when comparing the values of vibration accelerations and comfort indicators with railway standards - that the Moderus Beta tram on the reference section of the track could be considered as a very comfortable vehicle.*

**Keywords:** Tram, vibrations, comfort

---

## To cite this article:

Bakinowski, L., Firlik, B., (2022). Influence of the type of place occupied by a tram passenger on the ride comfort. Archives of Transport, 63(3), 49-58. DOI: <https://doi.org/10.5604/01.3001.0015.9176>



---

## Contact:

1) lukasz.bakinowski@doctorate.put.poznan.pl [<https://orcid.org/0000-0002-6604-3893>] – corresponding author;  
2) bartosz.firlik@put.poznan.pl [<http://orcid.org/0000-0003-3355-5451>];

## 1. Introduction

In Poland, in order for a given type of tram to be allowed for traffic, it must obtain approval, the rules of which are set out in the Regulation of the Minister of Infrastructure of 28 January 2011. However, it lacks specific requirements regarding the vibration level in vehicles. The word “vibration” appears once in the entire regulation and refers to external noise. On the one hand, it is a significant help for vehicle manufacturers, as vehicles do not have to be tested for vibration and comfort. On the other hand, the lack of an in-depth manufacturer’s analysis may reduce passenger comfort, especially when a vehicle with a high level of vibrations is allowed to run in the city.

There are railway standards describing the conditions in which a given rail vehicle may be allowed to operate, which include, among others, Standard PN-EN 14363 + A1: 2019-02E for testing and modeling the dynamic properties of rail vehicles before being allowed to run. It applies to railway vehicles, locomotives, freight and passenger carriages, empty and loaded. The passenger car is the closest to the tram, for which the permissible effective values of vibration acceleration in the transverse and vertical axis are 1.5 and 2.0 m/s<sup>2</sup>, respectively. However, the standard cannot be applied directly to tram-type vehicles. The Standard PN-EN 12299:2009 specifies methods of assessing comfort in rail vehicles. Again, however, it cannot be used directly for trams - it is necessary to modify the assumptions of the test method (e.g. driving speed or the length of the measuring window). Depending on the obtained results, it can be assessed with a given indicator whether, for example, a rail vehicle is comfortable or uncomfortable for a passenger (5-point rating scale, according to Table 1).

There are different methods for assessing the comfort level in rail vehicles, among others Mean Comfort Method (Dumitriu M., Stanica, 2021), Sperling’s Method (Jiang et al, 2019), Optimal Identification, Transfer Function (Cavacece M., 2022).

For trams, there is no European standard regulating the permissible vibration level. Depending on the country, vibration and noise tests are regulated by local regulations and documents, such as, for example, the German BOStrab (1987) and the German VDV recommendations, including recommendation No. 154 (2022) relating to noise measurements.

Table 1. Comfort assessment according to the  $N_{MV}$  index

Value of the $N_{MV}$ index	Description
$N_{MV} < 1.5$	Very comfortable
$1.5 \leq N_{MV} < 2.5$	Comfortable
$1.5 \leq N_{MV} < 3.5$	Medium
$1.5 \leq N_{MV} < 4.5$	Uncomfortable
$N_{MV} \geq 4.5$	Very uncomfortable

However, scientists and authors of the publication also tried to deepen the topic of vibrations in public transport vehicles. Research in the field of vibration comfort in light rail vehicles was carried out, among others, in Kraków (Król and Szczygieł, 2009). The vibrations on the floor of 105Na and NGT6 trams were tested, while driving without passengers, and the effective value of vibration acceleration was used for the evaluation, in accordance with the ISO 2631: 1997 standard.

A similar test was carried out in Lublin on the route of the bus line no. 18 and the route of the trolleybus line no. 160 (Merkisz and Tarkowski, 2012).

The vibration level of 35 different NGT 6 trams were performed under real operating conditions in Kraków (Zajac, 2011). All measurement points of vibration acceleration were located on passenger seats. The aim of the research was not to compare the vibrations between individual points of the tram, but to treat them as the same and to test the vibration level globally for the entire vehicle, on a selected measurement route.

In the Algerian town - Constantine the Alstom ARPEGE 350 M trams were evaluated in terms of comfort, but only based on surveys conducted among the city's residents, without the use of sensors (Khelf and Boukebbab, 2016). As many as 39.6% of 250 respondents considered the vibrations in the vehicle to be annoying. It was found based on passengers' feelings that the level of vibrations in the vehicle was variable and dependent on a specific route section.

In Croatia, the T3PVO (CKD Praha) and TMK2200 (Koncar KEV) trams were tested in terms of passenger comfort (Haladin et al., 2019) The analyzed parameters were accelerations on the tram floor in 3 directions (vertical, transverse and longitudinal). The parameters were used to calculate the ride comfort of standing passengers.

The RMS value of the vibrations was considered useful not only for the assessment of the vibration level and comfort (Wawryszczuk and Kardas-Cinal, 2021) but also for evaluation of the efficiency of tram articulations (Nowakowski et al, 2017).

The link between the vibration level and noise was also found to be useful information (Haladin et al, 2021). The tests on trams of the 105N type in order to assess the noise in the passenger space, and thus the passenger's comfort, were carried out in Katowice too (Michta and Haniszewski, 2018). Noise level in tramway vehicles was also assessed in Romanian city Timisoara. Sound level and frequencies were verified (Bacria et al, 2018).

In addition to directly examining passenger comfort, some research is also focused on the influence of the light condition of a rail vehicle on the level of vibrations while driving (Firlík and Czechyra, 2014). The online monitoring system for the condition of a light rail vehicle using information from installed sensors was to be used to monitor, among others, wear of suspension elements, damage to the wheel tread, current assessment of running stability, driving comfort, and safety against derailment.

Vibration transducers, which were mounted on the 105N tram, allowed for the analysis of the bogie's vibration transmissivity in relation to the vehicle body (Czechyra et al., 2011). It was noticed that the design and the degree of wear of the running gear have a significant impact on the amount of energy transferred from the running gear to the car.

The vibroacoustic approach was also used during the measurements of the Inspiro and Metropolis vehicles (Chudzikiewicz et al., 2016) in order to evaluate their dynamic properties. The analysis of the acoustic signal generated by the driving systems allowed for the conclusion that in the case of Inspiro, high-frequency components are excited, which was not observed in the case of the Metropolis vehicle.

Vibration acceleration used for identification of lateral rail irregularities was tested on a rail track and

rail vehicle intelligent monitoring system. Experiment was performed on the route between two Polish cities: Krakow and Wadowice (Uhl et al., 2010).

Studies were conducted to determine if the comfort of passenger is affected by the noise and vibration level of the Alstom CITADIS 402 (Khelf and Boukebbab, 2018), and also the ride discomfort caused by velocity fluctuation with proposal of the RDI (ride discomfort index) (Wang et al., 2001). In Poznań, which is another Polish city, the measurements were also connected with the internal noise of trams: 105N/105Na, Duewag GT6/GT8 and Tatra RT6-N1 (Tomaszewski and Orczyk, 2007). In Poznań there was also the trial of the implementation of on-board data recorders and their use to evaluate passenger ride comfort in city buses (Merkisz et al., 2012). The system to evaluate comfort in public transportation was also tested in South America, Brazil, where measurement on buses were carried out with the use of three-axis vibration transducers (Castellanos et al., 2011).

The conducted literature analysis showed that in the absence of applicable legal regulations in this area, individual cities perform the assessment of tram ride comfort using various methods. Vibration level was measured in various vehicles and various cities all over the world. This paper presents the method used in Poznań for the Moderus Beta tram, produced by Modertrans Poznań, which is currently the supplier of the largest number of vehicles for MPK Poznań.

## 2. Methods

### 2.1. Research object

The test object is Moderus Beta MF 02 AC tram (Fig. 1), one of the most popular trams in Poznań, manufactured by Modertrans Poznań Sp. z o.o. for many Polish cities. The vehicle in Poznań was delivered in various configurations and versions as a one-directional vehicle (MF 02 AC, MF 20 AC) and a bi-directional vehicle (MF 22 AC BD).

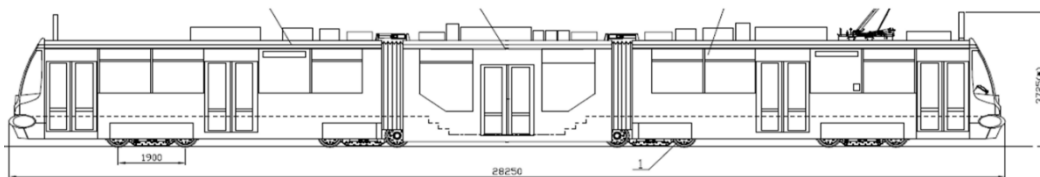


Fig. 1. Tram Moderus Beta MF 02 AC for the city of Poznań (source: Modertrans Poznań)

Moderus Beta MF 02 AC is partially low-floor tram, in which the external sections are high-floor, and the middle - low-floor. The area of the low-floor part constitutes 24% of the total floor area of the tram. The vehicle is based on four bogies with classic wheelsets. Each bogie has two motors and two gearboxes (on each axle of the vehicle).

## 2.2. Research methodology

The methodology was divided into preliminary and main research. The purpose of the preliminary tests was to verify whether the vibration level on individual seats is similar or perhaps significantly different, and whether any particular seat will experience the highest values of vibration acceleration. The preliminary test was carried out on one tram while driving at a constant speed of 40 km/h on the same straight section on the test track (Poznań, Franowo depot). The instantaneous values of vibration accelerations occurring in selected 8 measurement points, shown in Figure 2, located on the seats in the first and third vehicle section.

Then, the basic tests were carried out, the purpose of which was to verify whether the same level of vibrations would be observed in vehicles of the same type. It was initially assumed that the greatest vibrations in the vehicle would occur directly above the center of the bogie, i.e. the centre pin, while the smallest between bogies. In each of the 3 tested Moderus Beta MF 02 AC vehicles, 3 measuring points were located: two on the floor, one above the turning pivot of the third bogie, and the second between the third and fourth bogie (in the middle). One

measurement point was also located on the passenger seat, which in preliminary tests showed the occurrence of high effective values of vibration acceleration. The measurement points included in the actual tests are shown in Figure 3.

## 2.3. Measuring Equipment

The measurement path consisted of the following elements:

- 3-axis piezoelectric vibration transducers type 4524-B, by Bruel & Kjaer,
- input module type 3050-A-060, 50kHz, by Bruel & Kjaer,
- converter from direct current with a voltage of 24V to alternating 230V,

The BK Connect program was used to read and process the measurement results. A bandpass filter was used, which limits the frequency range to the range of 0.4 Hz - 100 Hz, because in this band, according to the standard, passenger comfort is considered (Standard PN-EN 14363+A1:2019-02).

## 3. Results

### 3.1. Preliminary measurement results

Table 2 presents the effective values of vibration accelerations at the given measurement points and directions. The highest effective values of vibration acceleration were distinguished by points 5 (along the Z axis) and 7 (along the Y axis). Point 5 was selected for further analysis, i.e. the seat at the level of middle of the third bogie.

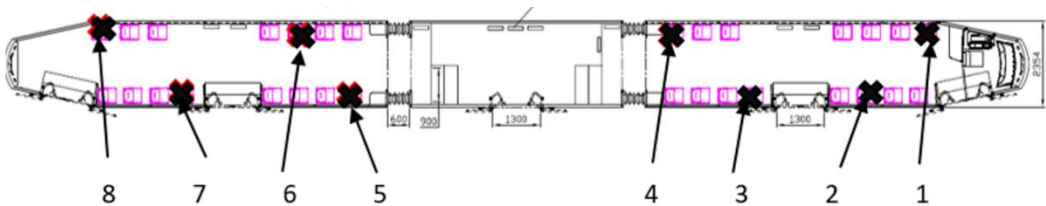


Fig. 2. Distribution of measuring points, preliminary tests

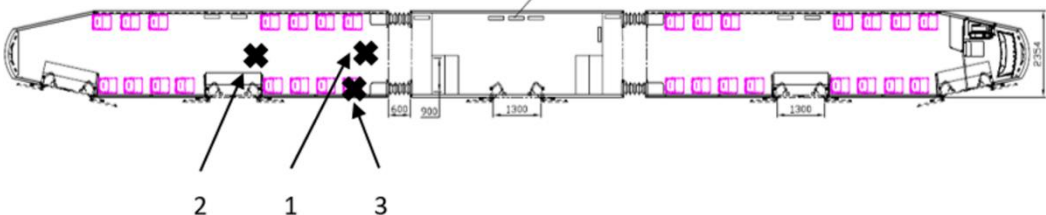


Fig. 3. Distribution of measuring points, main tests

Table 2. Effective vibration values measured at the given measuring points and axes, given in  $m/s^2$

	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8
Axis X	0.13	0.10	0.10	0.13	0.12	0.09	0.13	0.14
Axis Y	0.16	0.14	0.15	0.12	0.14	0.11	0.22	0.11
Axis Z	0.17	0.16	0.18	0.21	0.26	0.15	0.19	0.13

Figure 4 shows examples of the acceleration values of vehicle vertical vibrations in selected 2 seconds of movement. A low-pass filter with a cut-off frequency of 100 Hz was used in the analysis. It can be noticed that the maximum values of vibration accelerations are about  $0.75 - 1 m/s^2$ . The vibration level at all measurement points does not exceed  $1 m/s^2$ , the highest (instantaneous) values of vibration acceleration were observed at points 1, 5 and 6.

Figure 5 shows the acceleration values of the vehicle transverse vibrations in the selected 2 seconds of movement. It can be noticed that the maximum values of vibration accelerations are about  $0.5 - 0.7 m/s^2$ . The maximum amplitudes and the course of the vibrations are similar for most of the measurement points, but the highest was observed at point 8 (at a certain period of time even twice as high as for the other points).

For the signals collected at all measurement points, the comfort factors were also calculated in accordance with Standard PN-EN 12299 (2009) Table 3 shows example values for these calculations. The analysis shows that according to Standard PN-EN

12299 the vehicle is very comfortable,  $N_{MV}$  values much lower than 1.5, and no higher than 0.3.

Taking into account that the vibrations were measured "diagonally" in successive rows on the seats and assuming a similar level of vibrations on the left and right side seats at the same height, we can assume that all other seats in this vehicle are very comfortable. However, this would require an additional analysis which will be the subject of further research.

### 3.2. Main measurements results

The main measurements were carried out on the same test track in the Franowo depot and they were also carried out without passengers. Three different vehicles of the same type were tested on a straight track section at a constant speed of 40 km/h. The mileage of all tramways was similar (350 000 km for tram no. 1, 360 000 km for tram no. 2, and about 370 000 km for tram no. 3. The values in table 4 are the effective values of vibration accelerations from the entire run expressed in  $m/s^2$ .

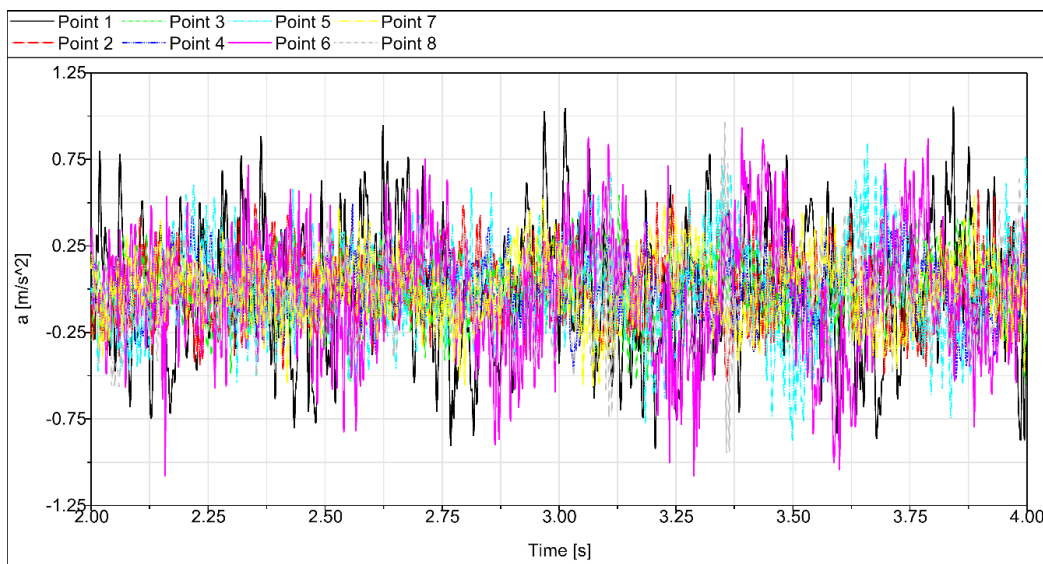


Fig. 4. Vertical vibrations at eight measuring points, preliminary tests

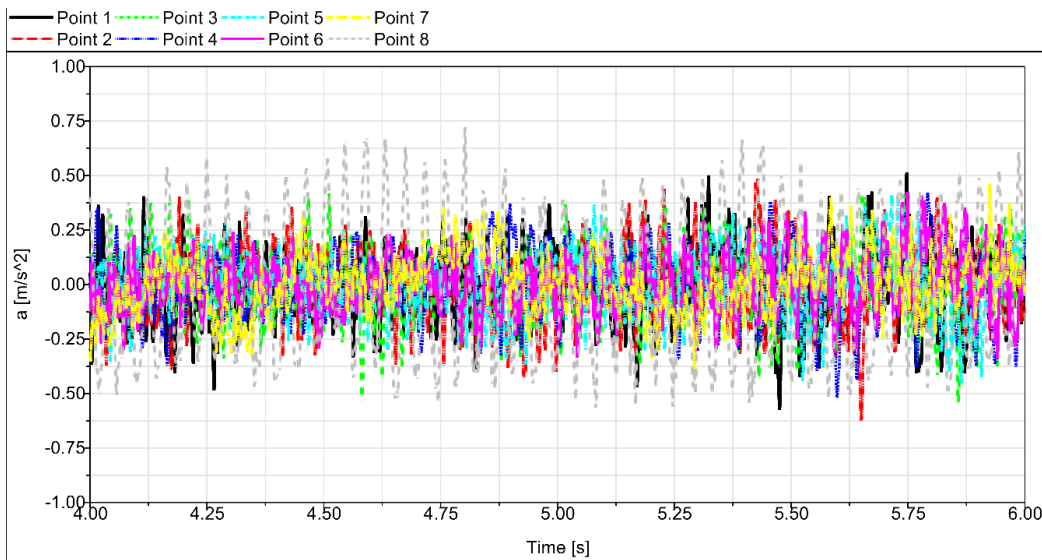


Fig. 5. Horizontal vibrations in eight measuring points of the preliminary test

Table 3. Comfort  $N_{MV}$  index

	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8
$N_{MVx}$	0.06	0.07	0.07	0.08	0.08	0.07	0.06	0.08
$N_{MVy}$	0.09	0.07	0.06	0.07	0.08	0.07	0.08	0.09
$N_{MVz}$	0.24	0.11	0.14	0.18	0.18	0.22	0.12	0.18
$N_{MV}$	<b>0.26</b>	<b>0.15</b>	<b>0.17</b>	<b>0.21</b>	<b>0.21</b>	<b>0.24</b>	<b>0.16</b>	<b>0.22</b>

Table 4. Main measurement results [ $m/s^2$ ]

Point	Axis	Tram 1	Tram 1	Tram 1	Tram 2	Tram 2	Tram 2	Tram 3	Tram 3	Tram 3
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9
1	Y	0.104	0.104	0.099	0.154	0.143	0.123	0.089	0.097	0.093
1	Z	0.362	0.351	0.363	0.223	0.268	0.257	0.409	0.373	0.390
2	Y	0.101	0.101	0.104	0.148	0.134	0.135	0.108	0.115	0.122
2	Z	0.184	0.200	0.213	0.210	0.240	0.207	0.211	0.207	0.210
3	Y	0.139	0.151	0.148	0.174	0.174	0.162	0.129	0.134	0.129
3	Z	0.275	0.297	0.292	0.235	0.247	0.256	0.210	0.203	0.213

Only the values of vibration accelerations in the vertical and transverse axes were checked in the actual tests, disregarding the longitudinal axis. Such a limitation was decided due to the fact that in urban traffic the values of vibration accelerations in the longitudinal axis are strongly influenced by the driving style of the vehicle driver, and in the case of measurements in city traffic, random events occurring on

the route, which could distort the measurement results. The values of the nine trips that were carried out as part of the tests of three different vehicles of the same type are summarized in Table 5. By T1.1, T1.2,... T3.3 successive tram runs are marked (measurements). The first three apply to tram no. 1, the second three to tram no. 2, and the last three to tram no. 3. The calculations show that the highest

effective value of vibration acceleration occurred at point 1 located on the floor above the pivot pin, in the vertical axis (Z). The highest resultant value (the Y and Z directions) also occurred in point 1.

Figure 6 shows a diagram of the vertical vibration accelerations of tram no. 1, successively for all measuring points in this vehicle. There is a noticeable reduction in the value of vibration accelerations for point 3, i.e. the passenger seat, which proves that the passenger seat absorbs the vertical vibrations coming from the vehicle's bogie well. Compared to point 1 (located above the pivot pin, on the floor), the vibration acceleration values are about 2 times lower. A similar relationship occurred for each tram and each journey.

The vibrations of point no. 1 (on the floor above the pivot pin) are the highest in tram no. 2, and the lowest in tram no. 1. Tram no. 1 was the vehicle with the lowest mileage among the tested and the newest tested tram vehicle.

Based on frequency analysis it has been noticed that in the case of tram no. 2 for a frequency of about 4 Hz there is a sharp and significant increase in the value of the acceleration of transverse vibrations, which can be justified by the excitation of the resonance frequency of the tram element. Due to the fact that the measuring point was above the center of the bogie of the vehicle, it can be concluded that the cause lies in one of the elements of the tram's running system, which should be further explored.

Table 5. Analysis of the results, main research

Point	Axis	T 1.1	T 1.2	T 1.3	T 2.1	T 2.2	T 2.3	T 3.1	T 3.2	T 3.3	Mean	Resultant
1	Y	0.104	0.104	0.099	0.154	0.143	0.123	0.089	0.097	0.093	0.112	0.351
1	Z	0.362	0.351	0.363	0.223	0.268	0.257	0.409	0.373	0.390	0.333	
2	Y	0.101	0.101	0.104	0.148	0.134	0.135	0.108	0.115	0.122	0.119	0.240
2	Z	0.184	0.200	0.213	0.210	0.240	0.207	0.211	0.207	0.210	0.209	
3	Y	0.139	0.151	0.148	0.174	0.174	0.162	0.129	0.134	0.129	0.149	0.289
3	Z	0.275	0.297	0.292	0.235	0.247	0.256	0.210	0.203	0.213	0.248	

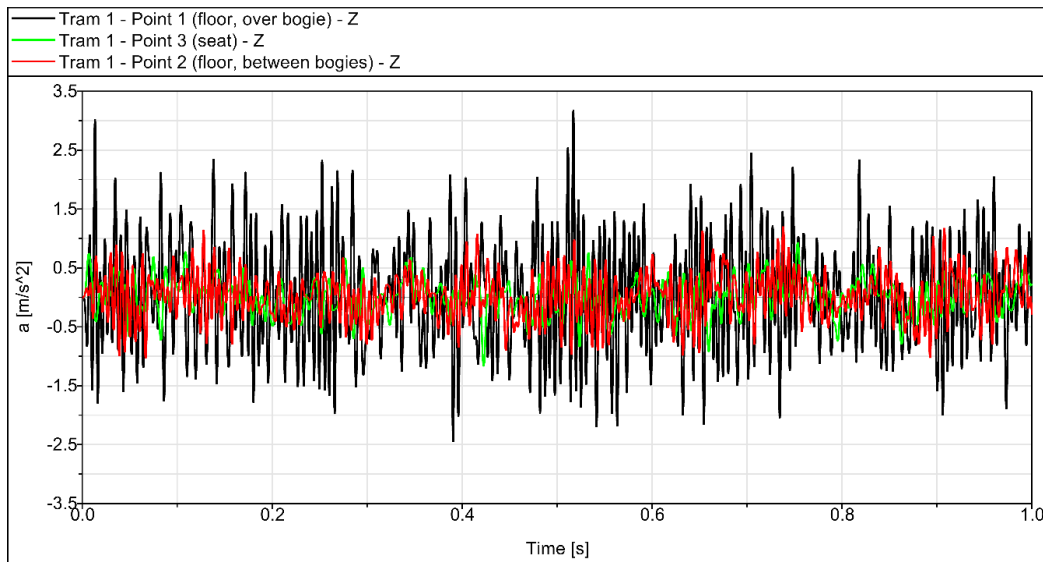


Fig. 6. Comparison of the vibration accelerations of the tram no. 1 measuring points

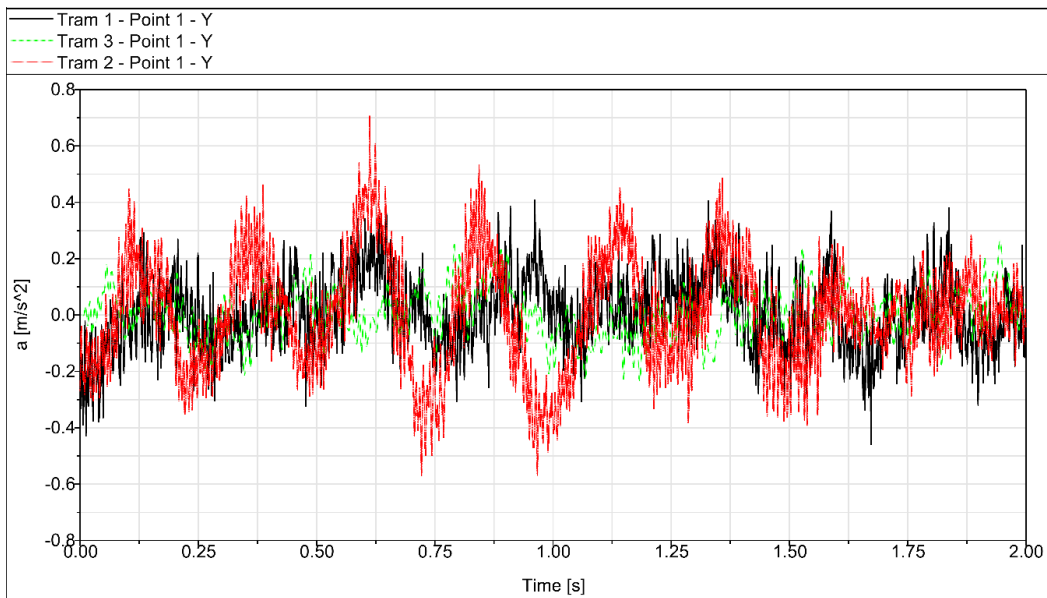


Fig. 7. Horizontal vibrations - specific measurements - point 1.

#### 4. Summary

The work concerned the measurement of vibrations in the Moderus Beta MF 02 AC tram. Initial tests were first carried out to verify the level of vibrations in the seats and to identify seats with a higher level of vibrations. Eight seats in the tram were tested in three axes (longitudinal, transverse, vertical). Then, tests were carried out to verify vibrations in three points of the vehicle: on the floor above the pivot pin, on the floor in the middle between the bogies and on the seat, because it is these tram components (floor and seats) that directly transmit the vibrations to the passenger. During the actual tests, the measurements were collected along the transverse and vertical axis. The results from three measuring points and three different trams of the same type were compared.

Based on the results and the analysis, the following conclusions were drawn:

1. The highest vibrations felt by a passenger in a Moderus Beta MF 02 AC tram occur on the floor above the middle of the bogie. This dependence occurs in most trams, regardless of their type.
2. The vertical vibrations on the floor above the pivot pin in the Moderus Beta MF 02 AC tram are twice as high as the vertical vibrations on

the seat located at the same pivot pin, which shows a significant tendency to damp vertical vibrations by the passenger seat in the vehicle.

3. On the tested section of the test track, the Moderus Beta MF 02 AC tram traveling at a speed of 40 km/h is a very comfortable vehicle for a seated passenger (assessed as a passenger car in accordance with PN-EN 12299),
4. Comparing with the PN-EN 14363 + A1: 2019-02 standard, the effective values of vibrations occurring in the Moderus Beta MF 02 AC tram traveling along the test track section at a speed of 40 km/h are about ten times lower than the permissible values in passenger carriages.
5. The vibration level in trams of the same type differs depending on the specific vehicle. One of the trams showed an almost 2 times higher level of vibrations in the transverse direction (Y). The lowest level of vibrations was observed in the tram with the lowest mileage. As the mileage increases, the driving comfort in the vehicle decreases. A noticeable sudden change in the Y direction came after the vehicle had reached a mileage of 370,000 kilometers. Other vehicles of this type would need to be verified to determine if the mileage relationship is reproducible.



6. In the Moderus Beta MF 02 AC vehicle the level of vibration acceleration in the transverse direction is lower than in the vertical direction.
7. Recorded attempts to drive the same tram on the same test track at the same speed allowed to obtain very similar results, and thus high repeatability and reliability were obtained.

Thanks to the conducted study, it was possible to assess the level of vibrations in the Moderus Beta tram, to compare the level of vibrations on the floor and on the passenger seat, as well as to compare three different trams of the same type in terms of vibrations occurring in them.

The analysis included in this article showed that each of the three verified vehicles of the same type showed different running properties. Due to the lack of applicable standards for the assessment of running properties of trams (both new and already in operation), it seems necessary to develop such a methodology, reflecting the actual operating conditions of trams. Striving to expand knowledge in this area will enable enterprises producing trams to create a higher quality product, and communication companies to verify and reliably evaluate the purchased vehicles.

### Acknowledgment

The research was carried out under the Applied Doctorate Program of the Ministry of Education and Science implemented in the years 2021-2025 (Agreement no. DWD / 5/0009/2021)

The presented results have been co-financed from the subsidies appropriated by the Ministry of Education and Science of the Republic of Poland - 0416/SBAD/0004.

### References

- [1] Bacria V., Ghita E., Herisanu N., (2018). On Acoustic Comfort in Urban Transport on Rails, Springer International Publishing AVMS-2017, 198, 83-90.
- [2] BOStrab (Verordnung über den Bau und Betrieb der Straßenbahnen, Straßenbahn-Bau- und Betriebsordnung), 11.12.1987.
- [3] Castellanos, J.C., Susin, A.A., Fruett, F. (2011) Embedded sensor system and techniques to evaluate the comfort in public transportation. Proceedings of the 14th International IEEE Conference on Intelligent Transportation Systems, 1858-1863.
- [4] Cavacece M., (2022). Comfort Assessment in Railway Vehicles by an Optimal Identification of Transfer Function. *Universal Journal of Mechanical Engineering* 10(1), 1-12.
- [5] Chudzikiewicz, A., Stelmach, A., Wawrzyński, W., Firlík, B., Czechyra, B. (2016). Vibroacoustic evaluation of a light rail vehicle. Proceedings from the 23th International Congress on Sound & Vibration, Athens, 10-14.07.2016.
- [6] Czechyra, B., Kwaśnikowski, J., Tomaszewski, F. (2011). Possibilities of using vibroacoustic methods in the process of assessing the operational properties of a tram. *Logistyka – nauka*, 4, 172-180.
- [7] Dumitriu M., Stanica D. (2021). Study on the Evaluation Methods of the Vertical Ride Comfort of Railway Vehicle - Mean Comfort Method and Sperling's Method. *Applied Sciences*, 11, 3951, 1-25.
- [8] Firlík, B., Czechyra, B. (2014). On-line monitoring system of the technical condition of the infrastructure and running gear of a light rail vehicle. *Systemy transportowe*, 2, 6-10.
- [9] Haladin I., Vranešić K., Ivančev M. Lakušić S. (2021). Influence of tram vibrations on earthquake damaged buildings. 1st Croatian Conference on Earthquake Engineering 1CroCEE, 1583-1593.
- [10] Haladin, I., Lakušić, S., Bogut, M. (2019). Overview and analysis of methods for assessing ride comfort on tram tracks. *Građevinar*, 10, 901-921.
- [11] Jiang, Y.; Chen, B.K.; Thompson, C. (2019). A comparison study of ride comfort indices between Sperling's method and EN 12299. *International Journal of Rail Transportation*, 7, 279–296.
- [12] Khelf, M., Boukebbab, S. (2016). The effect of vibration inside the Constantine's tramway on the comfort of passengers. *Jve International Ltd. Vibroengineering Procedia*, 9, 33-38.
- [13] Khelf, M., Boukebbab, S. (2018). The effect of noise on the comfort of passengers inside the tramway and its impact on traffic congestion in the urban area. *Jve International Ltd. Journal Of Vibroengineering*, 20 (1), 530-540.
- [14] Król, S., Szczygieł, J. (2009). Research of vibration discomfort in selected trams. *Problemy Eksploatacji*, 2, 99-108.

- [15] Merkisz, J., Pielecha, J., Tarkowski, S. (2012). On-Board Data Recorders And Its Using To Evaluation Of Passenger Ride Comfort In City Buses. *Autobusy*, 5, 300-305.
- [16] Merkisz, J., Tarkowski, S. (2012). Dynamic factors and their impact on the subjective sense of comfort in city buses. *Postępy Nauki i Techniki*, 14, 169-178. ISSN 2080-4075.
- [17] Michta, A., Haniszewski, T. (2018). Traffic noise experienced on buses, trams and cars in the urban agglomeration of the city of Katowice. *Scientific Journal of Silesian University of Technology. Series Transport*, 98, 101-109.
- [18] Nowakowski T., Komorski P., Tomaszewski F. (2017). The efficiency of tram articulations compared to vibroacoustic emissions. *The Archives of Transport*, 44 (4), 56-63.
- [19] Regulation of the Minister of Infrastructure of 28 January 2011 on the scope, conditions, dates and manner of technical tests of trams and trolleybuses and units performing these tests.
- [20] Standard ISO 2631-1:1997 (Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 1: General requirements).
- [21] Standard PN-EN 12299:2009 (Railway applications - Ride comfort for passengers – Measurement and evaluation).
- [22] Standard PN-EN 14363+A1:2019-02 (Railway applications – Testing and Simulation for the acceptance of running characteristics of railway vehicles – Running Behaviour and stationary tests).
- [23] Tomaszewski, F., Orczyk, M. (2007). Ocena poziomu hałasu wewnątrz tramwajów na podstawie badań (The noise level assessment in the inside of the trains on the base of the tests). *Pojazdy Szynowe*, 4, 1-6.
- [24] Uhl, T., Mendrok, K., Chudzikiewicz, A. (2010). Rail Track and Rail Vehicle Intelligent Monitoring System. *The Archives of Transport*, 22 (4), 495-510.
- [25] VDV154 (Geraeusche von NahverkehrsSchienenfahrzeugen nach BOS-trab) 08/2022.
- [26] Wang, F., Ma, N., Inooka, H. (2001). A driver assistant system for improvement of passenger ride comfort through modification of driving behavior. *Proceedings from the International Conference on Advanced Driver Assistance Systems*, 483, 38-42.
- [27] Wawryszczuk R., Kardas-Cinal E., (2021). Analysis of ride comfort in selected types of rail vehicles. *Journal of KONBiN*, 51 (4), 157-170.
- [28] [www.modertrans.poznan.pl](http://www.modertrans.poznan.pl), Modertrans Poznań Sp. z o.o.
- [29] Zając, G. (2011). Badania hałasu i drgań w tramwajach. *TTS Technika Transportu Szynowego*, 18(9), 53-58.